Weak Triplet, Color Octet Scalars & the CDF Wjj Excess

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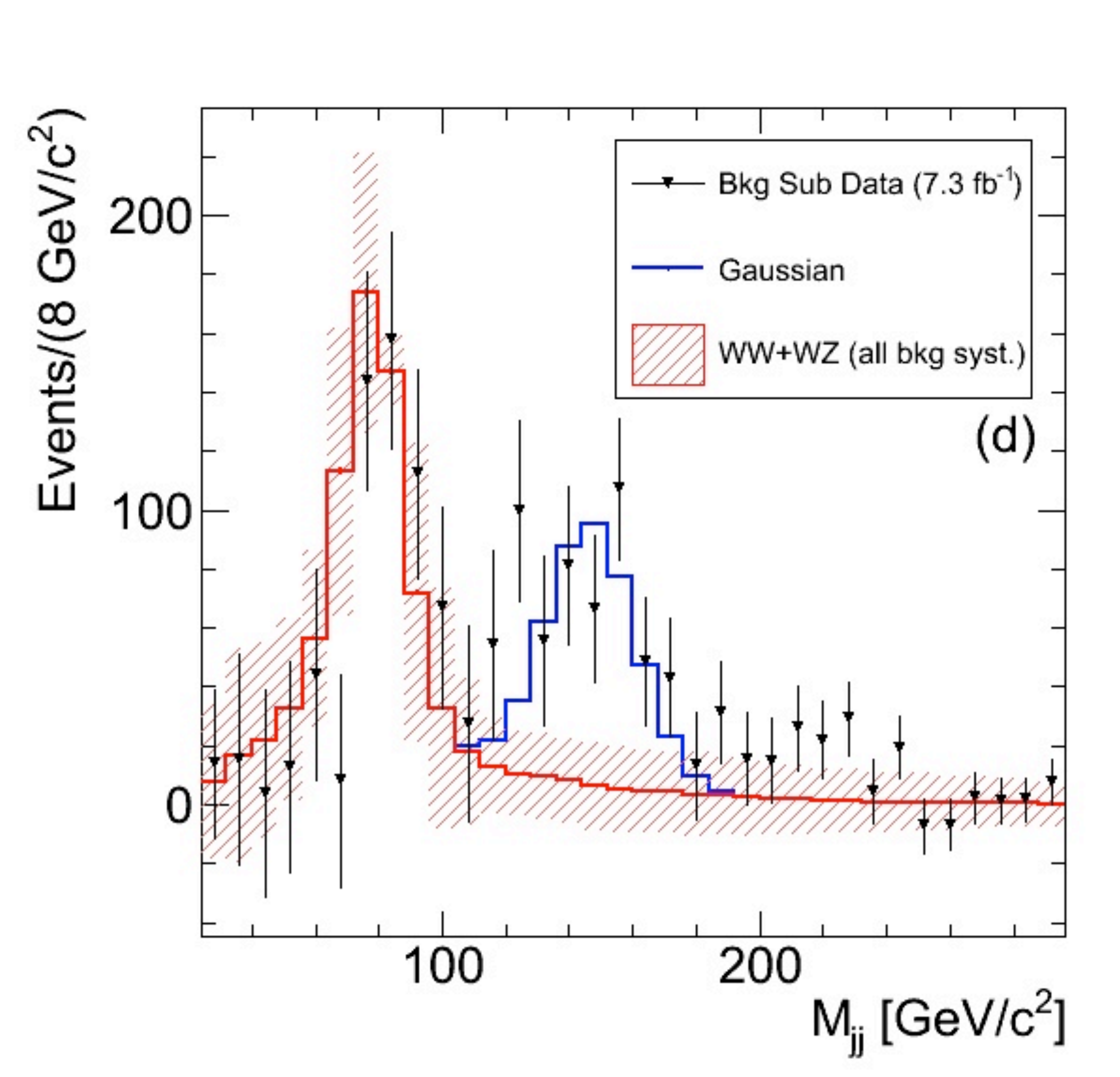
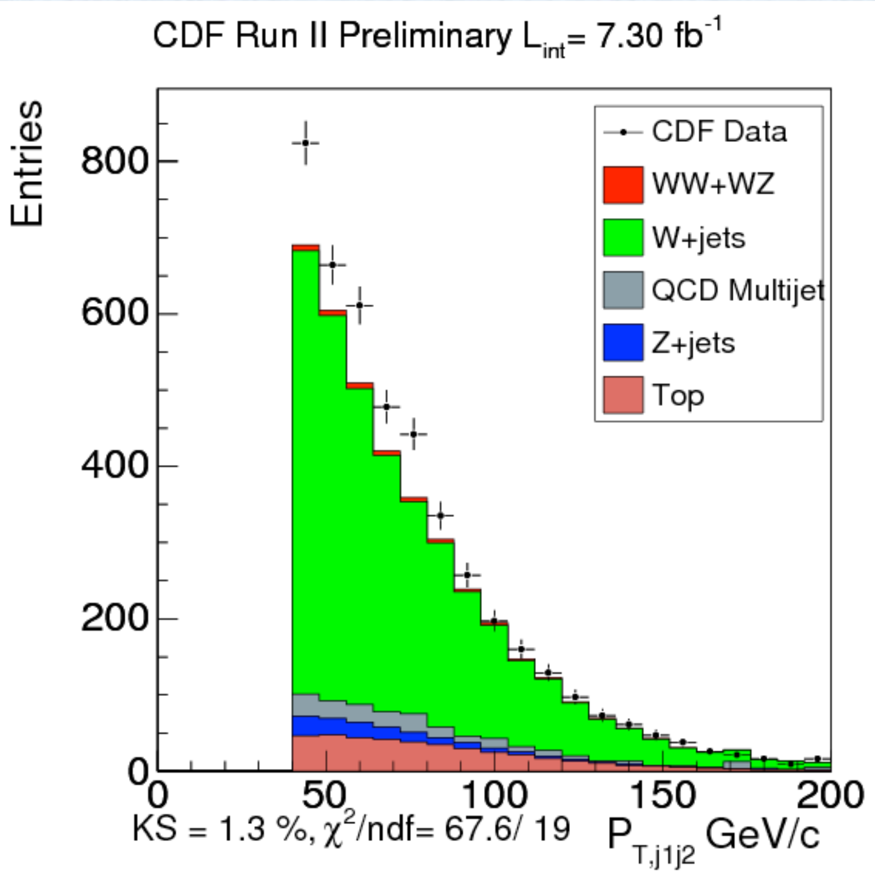
SUSY 2011

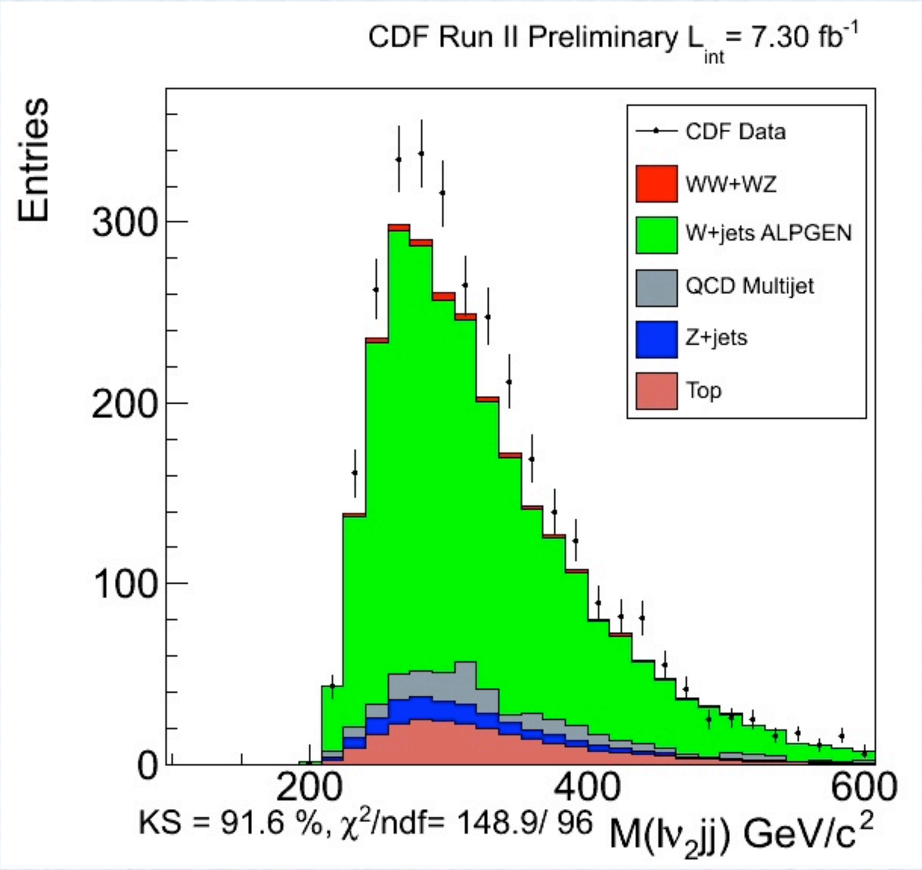
Preview

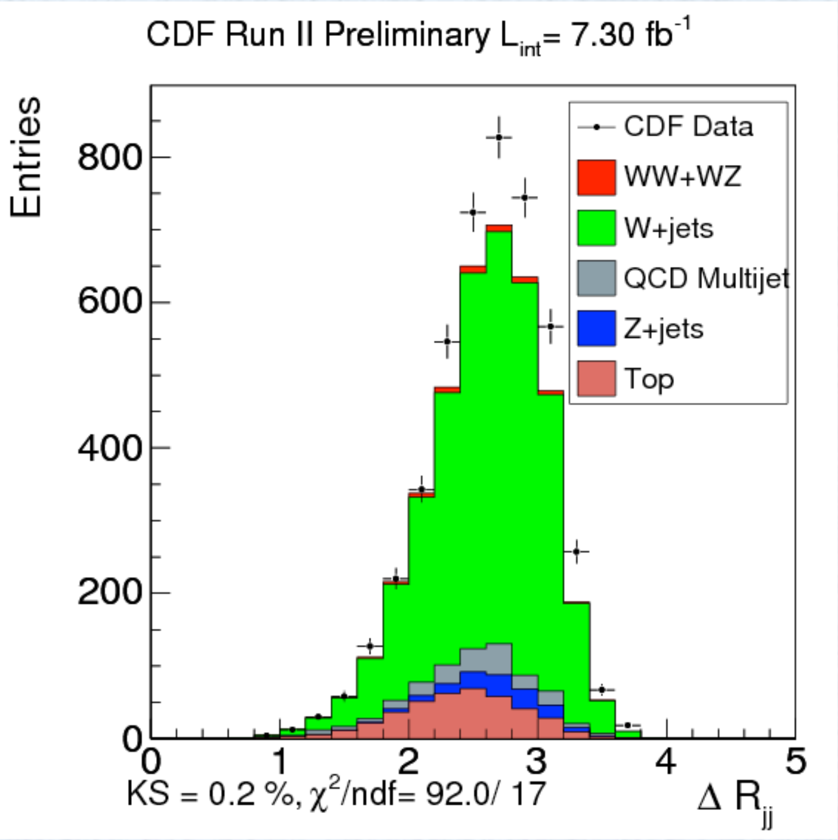


- CDF Excess
- "Octo-triplets"
- Extended Model
- Fitting Wjj bump
- Resonant Model
- Kinematic Plots

CDF: More Than Just Mjj

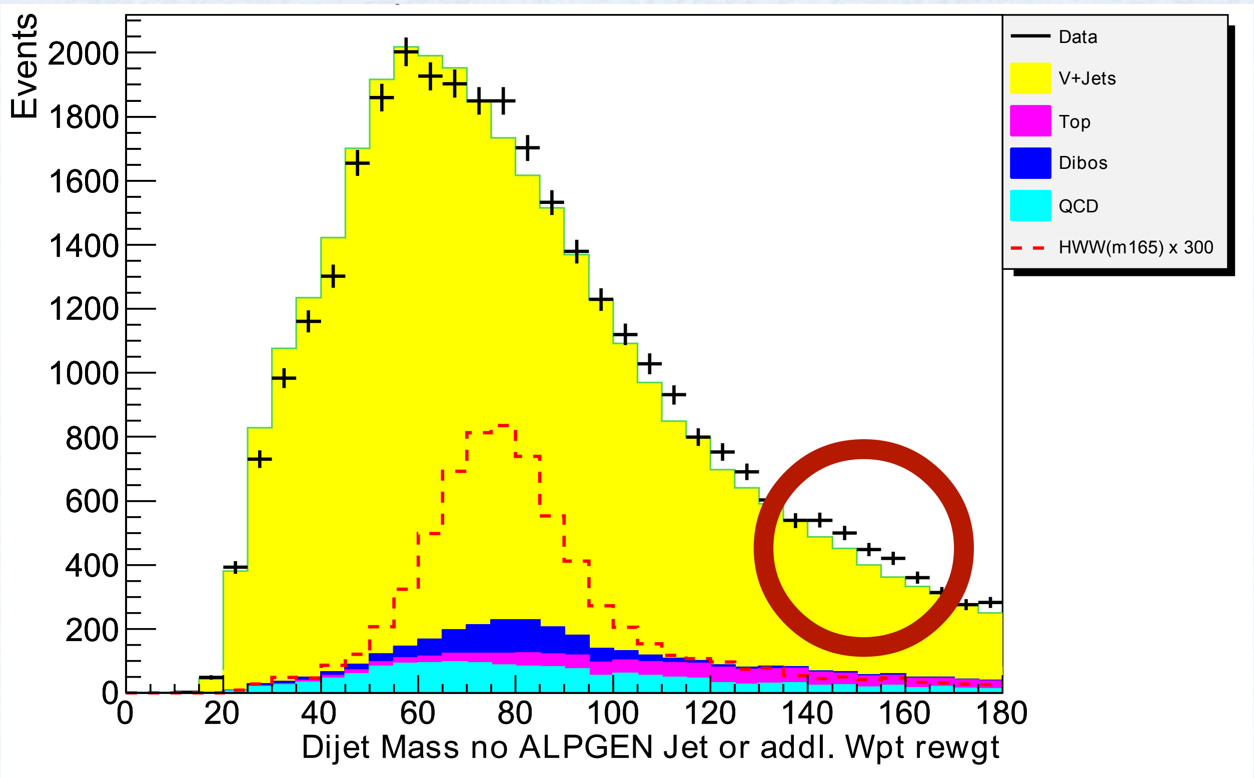


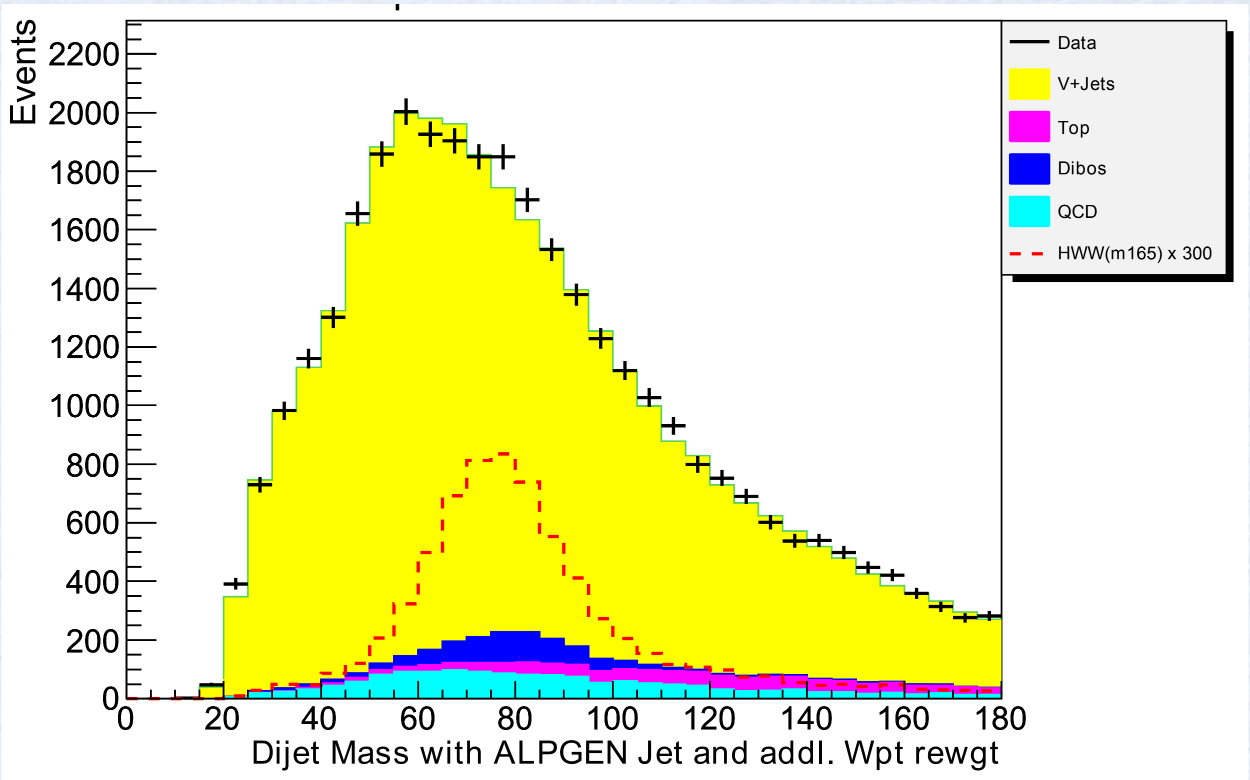




- Plots show large, consistent excesses in signal region where 115 GeV < Mjj < 175 GeV
- Sidebands consistent with SM predictions for all observables
- Significance of Mjj bump grows with harder PT cuts

D0 Claims Null Result, BUT ...





unreweighted **reweighted**

D0 Higgs search has similar feature near Mjj ≈ 150 GeV
(S. Zelitch PhD thesis 2010)

~3 sigma above BG in *unreweigted* sample with 5.4/fb

Controversy

- D0 may also be seeing bump near ~150 GeV in Wjj (Zelitch thesis)
- Larger D0 jet definition may veto signals with additional soft jets
- D0 null result corrects out-of-cone radiation and vetoes 3+ jet events
  - More high PT jets per event, more likely to veto signal (Buckley et. al. hep-ph/1107.5799)
- How does D0 signal change with different cuts?
- Will we see inclusive D0 plots? Other kinematic plots?

Our strategy: Interpret CDF signal as new physics




OCTO-TRIPLETS

$$\Theta^{a\alpha} : (8, 3, 0)$$

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$




Most General Renormalizable Lagrangian

$$\mathcal{L}_\Theta = \frac{1}{2} D^\mu \Theta^{a\alpha} D_\mu \Theta^{a\alpha} - \frac{1}{2} M_\Theta^2 \Theta^{a\alpha} \Theta^{a\alpha} - V(\Theta)$$

$$V(\Theta) \supset \mu_\Theta f^{abc} \epsilon^{\alpha\beta\gamma} \Theta^{a\alpha} \Theta^{b\beta} \Theta^{c\gamma} - \lambda_\Theta \left(\Theta^{a\alpha} \Theta^{a\alpha}\right)^2 + \cdots$$

Charge Eigenstates :

$$\Theta^{a\pm} \equiv \frac{1}{\sqrt{2}} (\Theta^{a1} \mp i \Theta^{a2}) \qquad \Theta^{a0} \equiv \Theta^{a3}$$

(Some) Gauge Interactions :

$$2igg_s f^{abc} G^{\mu a} \left(W_\mu^+ \Theta^{b-} - W_\mu^- \Theta^{b+}\right) \Theta^{c0}$$

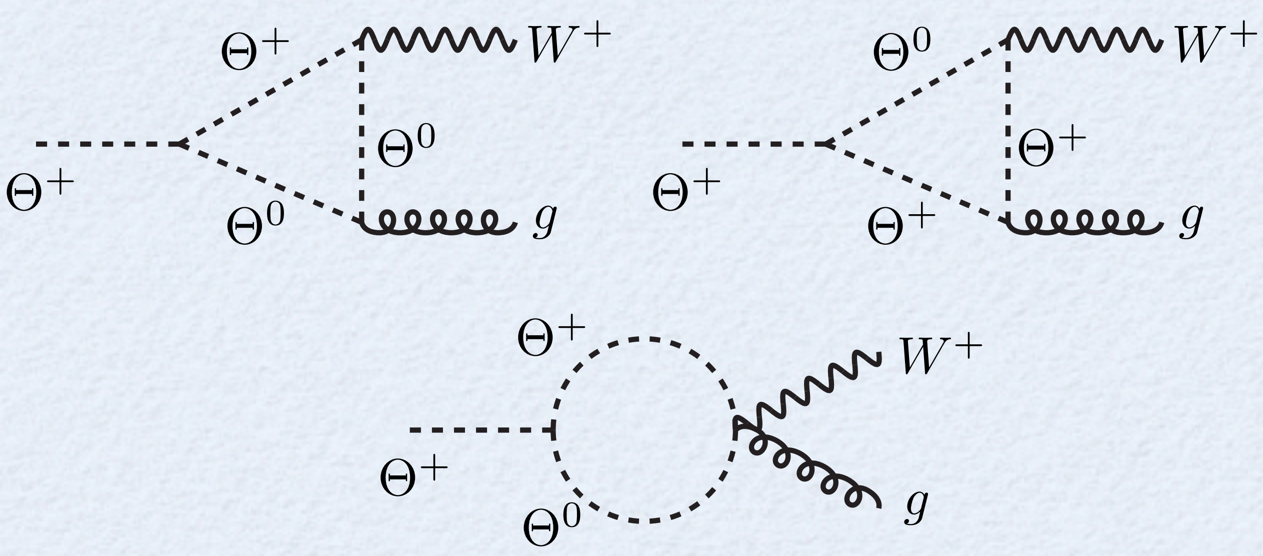
$$-igW_\mu^- \left[(\partial_\mu \Theta^{a+}) \Theta^{a0} - \Theta^{a+} \partial_\mu \Theta^{a0}\right]$$

Similar couplings to (WW), (ZZ), (Zg), (gg), (γγ)...

Charged Decays

For nonzero cubic term, the only decay is to dibosons at loop level

$$\Gamma\left(\Theta^{\pm} \to W^{\pm} g\right) \simeq \frac{\alpha \alpha_s \mu_\Theta^2}{\pi^3 \sin^2\theta_W M_\Theta} f(M_W/M_\Theta) \sim 10^{-7} \frac{\mu_\Theta^2}{M_\Theta}$$



Similar decays for neutral scalar (γg, Zg)
gg decays forbidden by gauge invariance

These widths are tiny. Can higher dimension operators compete ?

Integrate Out Vector-like Quark (ψ)

Most general ψΘ interactions

$$\mathcal{L}_{\Theta\Psi} = \Theta^{a\alpha}\,\overline{\Psi}_R\,T^a\,\frac{\sigma^\alpha}{2}\left(\eta_i Q_L^i + \eta_\psi \Psi_L\right) + \text{H.c.}$$

and mass terms

$$-m_\psi \overline{\Psi}_L \Psi_R - \mu_i \overline{Q}_L^i \Psi_R + \text{H.c.}$$

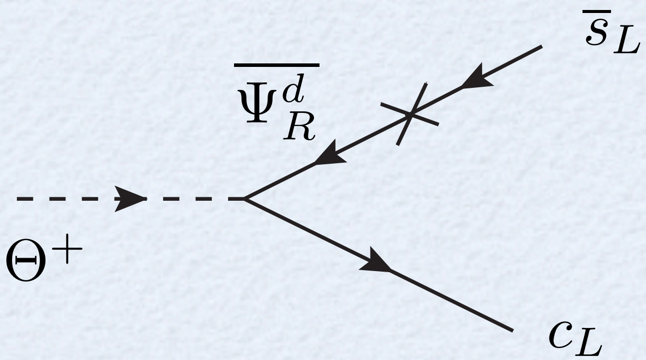
Integrate out ψ, use EOM in quark mass-eigenbasis

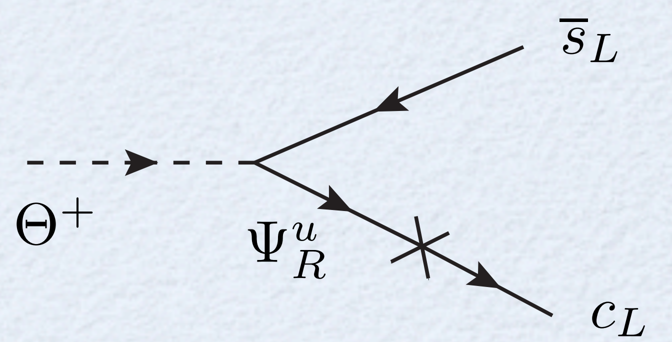
$$\frac{-i}{\sqrt{2}m_\psi}\,\Theta^{a+}\,\overline{U}^i T^a \left[(C\,V_{\text{KM}})_{ij}\,m_{d_j} P_R - m_{u_i}\left(C^\dagger\,V_{\text{KM}}\right)_{ij} P_L\right] D^j + \text{H.c.}$$

C is a matrix in flavor space and depends on Lagrangian parameters μ η, and m_ψ

New Dijet Decay Modes

Octo-triplets can now decay to jet pairs





$$\Gamma(\Theta^+ \to c\,\bar{s}) \simeq \frac{m_c^2 + m_s^2}{64\,\pi\,m_\psi^2}\,|C_{22}|^2 M_\Theta = 1.3{\times}10^{-6}\,\mathrm{GeV}\;|C_{22}|^2 \left(\frac{M_\Theta}{150\,\mathrm{GeV}}\right)\left(\frac{1\,\mathrm{TeV}}{m_\psi}\right)^2$$

Decays with mixed generation jets scale with different C's

$$\frac{\Gamma(\Theta^+ \!\to c\,\bar{b})}{\Gamma(\Theta^+ \!\to c\,\bar{s})} \simeq \frac{1}{|C_{22}|^2}\left(\frac{m_b^2}{m_c^2}\,|C_{23}|^2 + |C_{32}|^2\right),$$

3d generation dominates w/ top-mass enhancement, but kinematically forbidden if MΘ < mt + mb

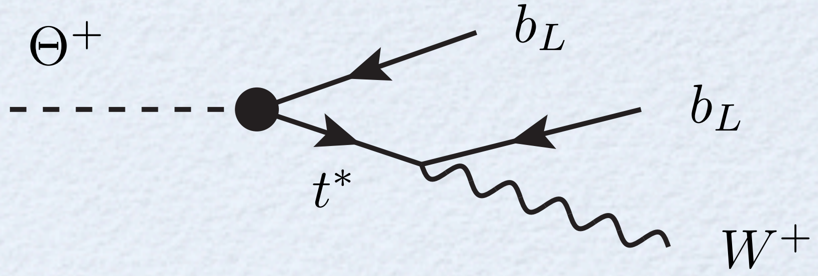
Real/Virtual Top Decays

For MΘ > Mt + Mb, dominant width is

$$\Gamma(\Theta^+ \to t\bar{b}) \simeq 2.2 \times 10^{-2}\,\text{GeV}\;|C_{33}|^2 \left(1 - \frac{m_t^2}{M_\Theta^2}\right)^2 \left(\frac{M_\Theta}{150\,\text{GeV}}\right)\left(\frac{1\,\text{TeV}}{m_\psi}\right)^2$$

For MΘ ≈ 150 GeV =>   3-body off-shell decay is important

$$\Gamma(\Theta^+ \to W^+ b\bar{b}) = \frac{\alpha\,|C_{33}|^2\,m_t^4}{64\pi^2 \sin^2\theta_W\,m_\psi^2}\mathcal{F}(M_\Theta)$$



Function arises from the phase-space integral

$$\mathcal{F}(M_\Theta) = \int_0^{E_0} d\overline{E}_{\bar{b}} \int_{E_0 - \overline{E}_{\bar{b}}}^{E_b^{\max}} dE_b\; \frac{E_b + (E_0 - \overline{E}_{\bar{b}})\left[\frac{2M_\Theta}{M_W^2}(E_0 - E_b) - 1\right]}{(M_\Theta^2 - 2M_\Theta \overline{E}_{\bar{b}} - m_t^2 + m_b^2)^2 + m_t^2\Gamma_t^2}$$

$$E_0 = \frac{M_\Theta^2 - M_W^2}{2M_\Theta} \qquad\qquad E_b^{\max} = \frac{E_0 - \overline{E}_{\bar{b}}}{1 - 2\overline{E}_{\bar{b}}/M_\Theta}$$

Competition

$$\Gamma(\Theta^+ \to W^+ b\bar{b}) \simeq 2.9 \times 10^{-6}\,\text{GeV}\,|C_{33}|^2 \frac{\mathcal{F}(M_\Theta)}{\mathcal{F}(150\text{ GeV})} \left(\frac{1\,\text{TeV}}{m_\psi}\right)^2$$

Compare with 2 body width

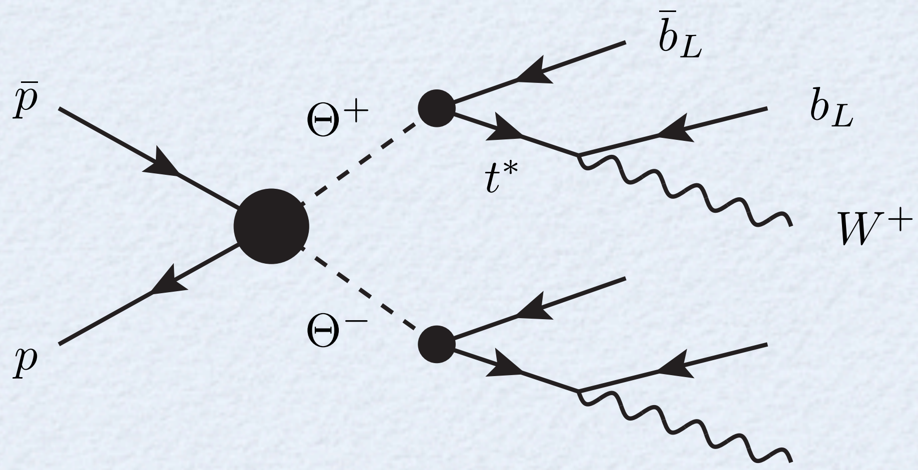
$$\Gamma(\Theta^+ \to c\,\bar{s}) \simeq 1.3 \times 10^{-6}\,\text{GeV}\,|C_{22}|^2 \left(\frac{M_\Theta}{150\,\text{GeV}}\right) \left(\frac{1\,\text{TeV}}{m_\psi}\right)^2$$

Natural inputs give automatic competition

Both dominate over loop-level diboson decays

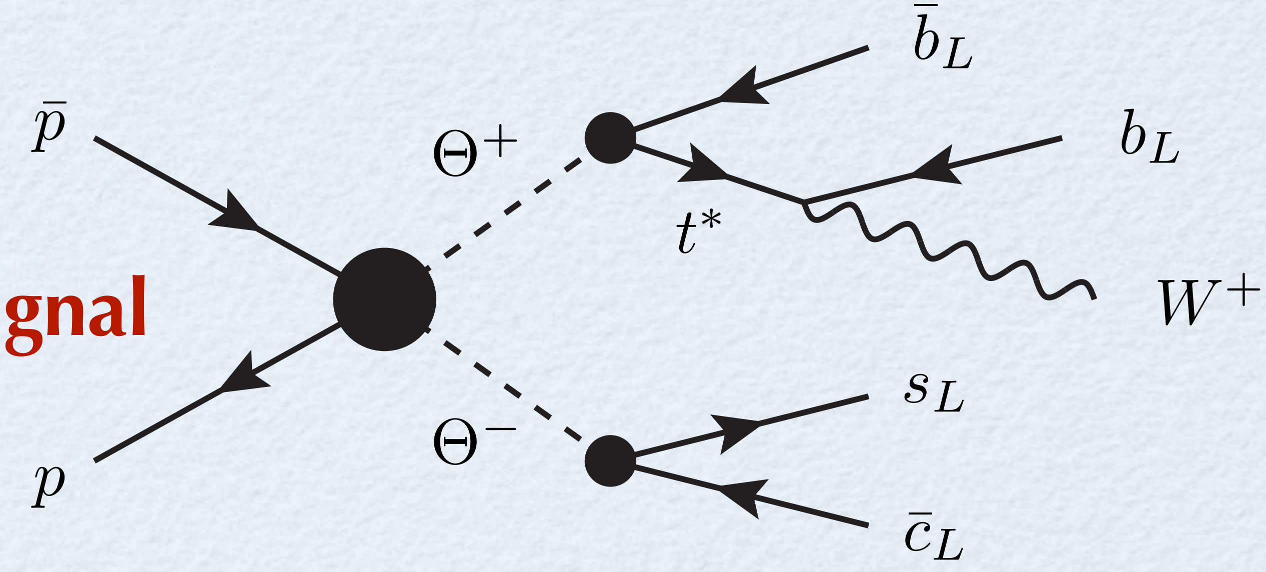
We ignore other decay modes for main results

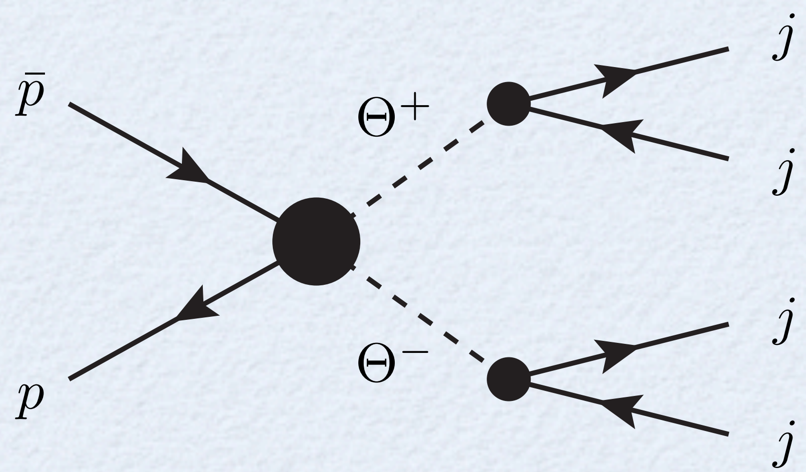
Dominant Collider Signals



WW + 4 jets signal.

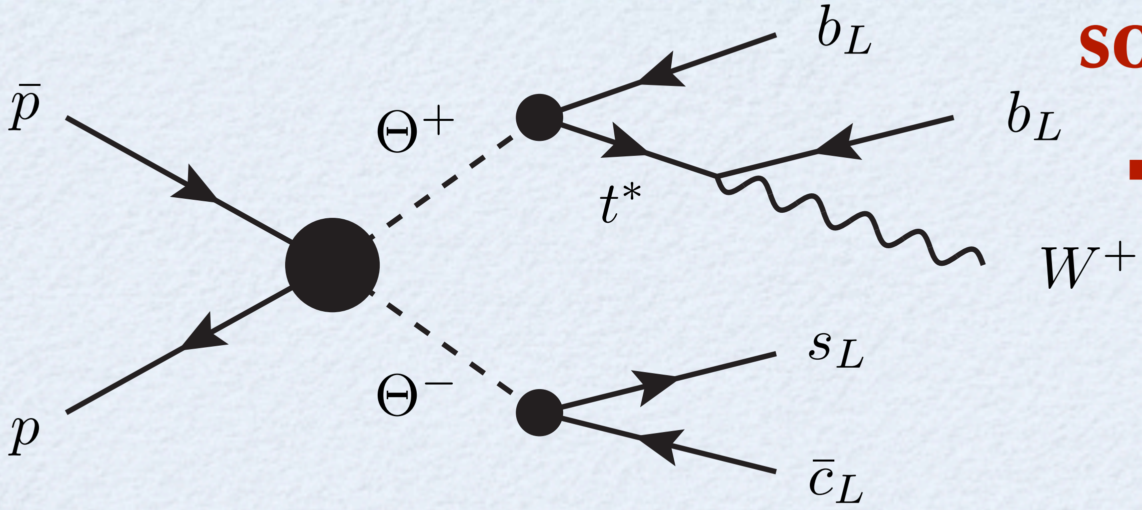
(Wbb)(jj) Light b-jets, effective W(jj) signal





4 jet signal

Looks Can Deceive



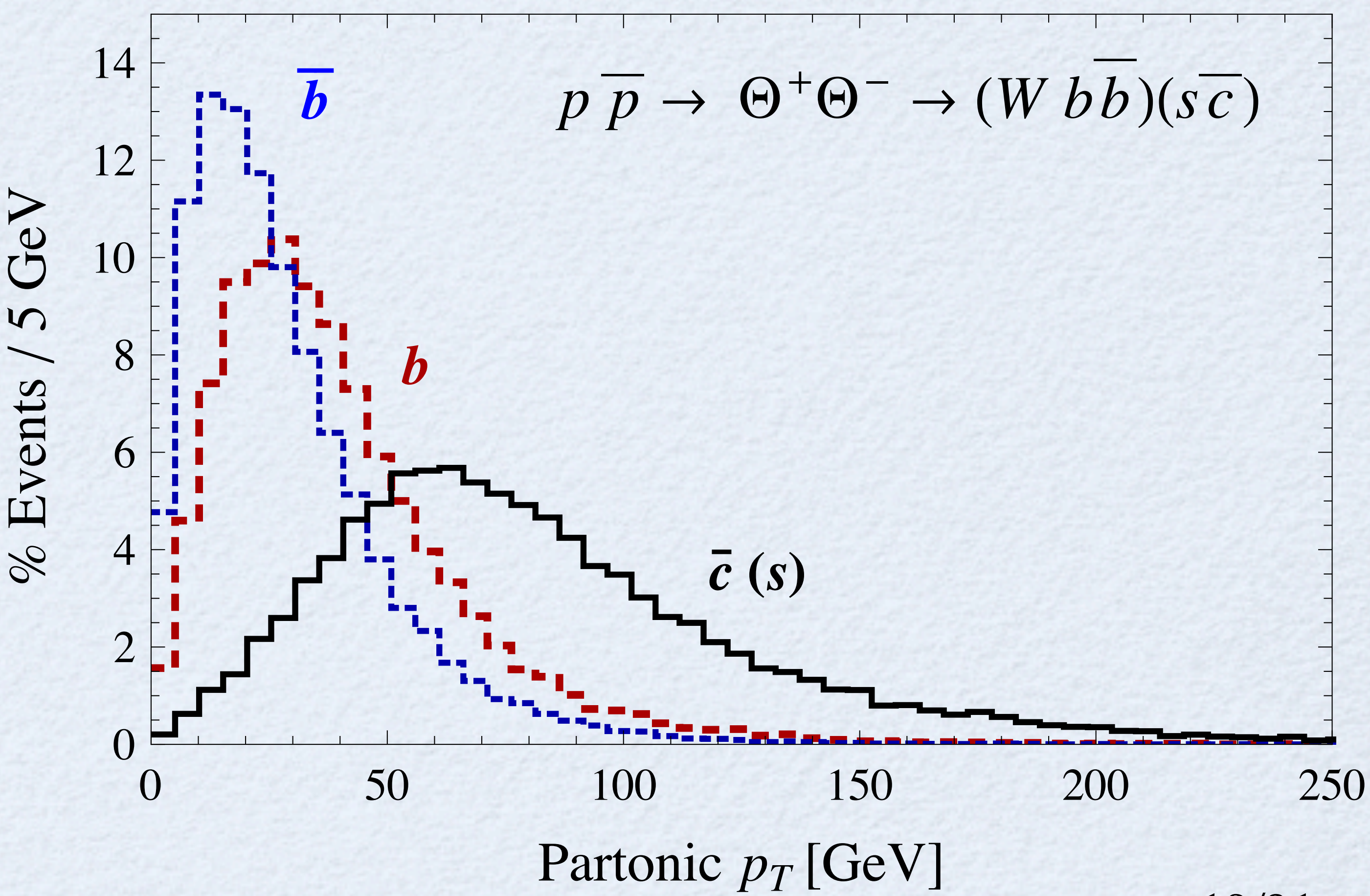
soft b-jets

Wjj survive cuts

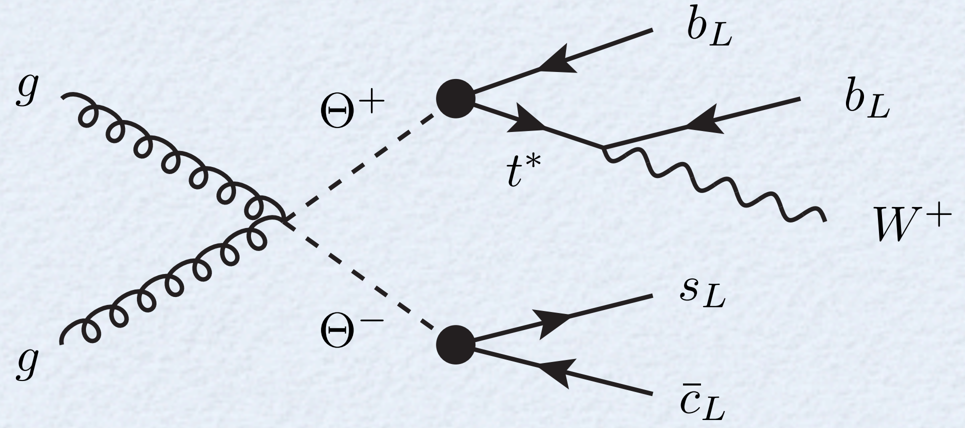
b-jets fall below PT cuts

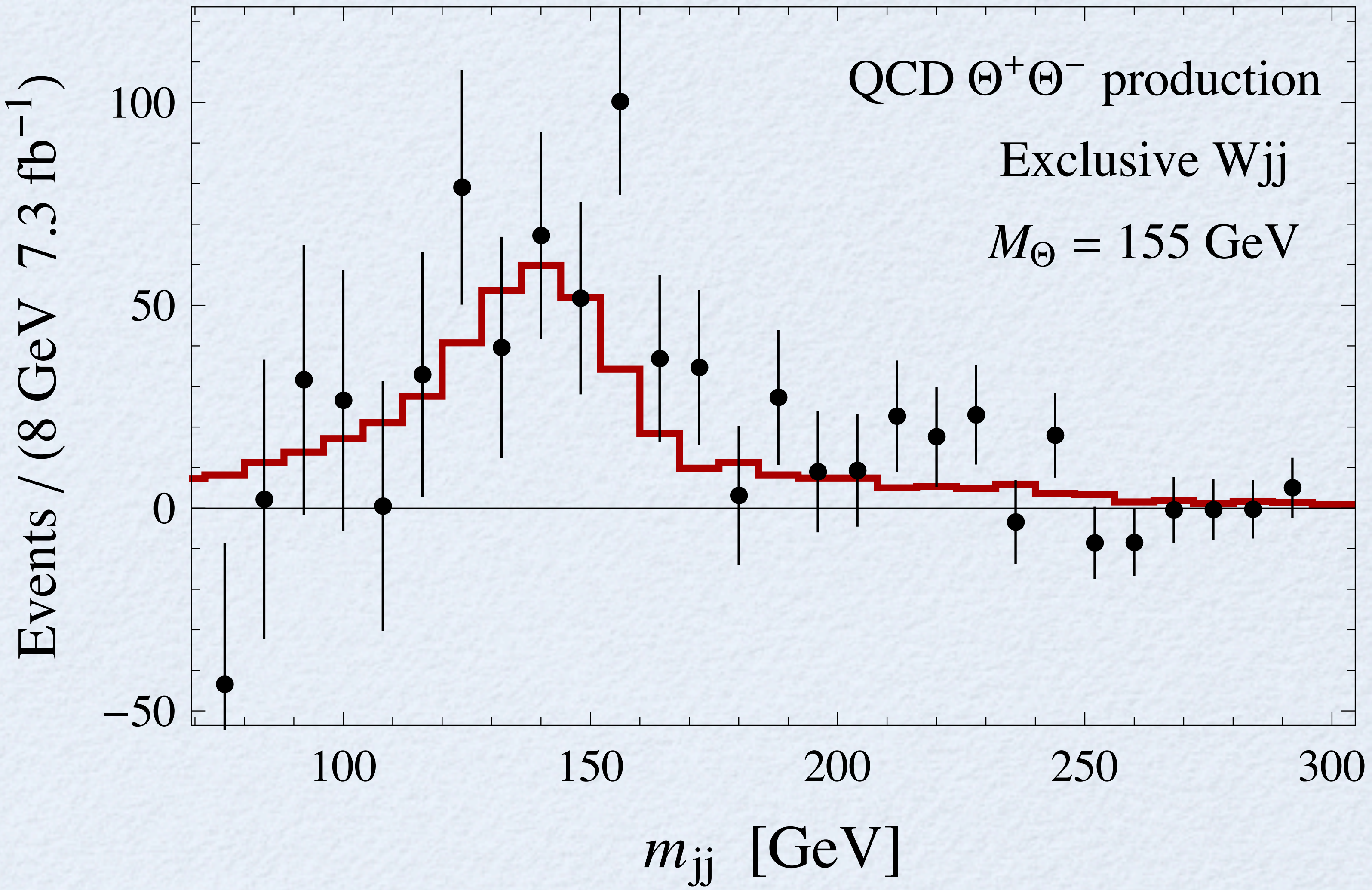
Effectively W+2 jet event

Similar effect occurs in loop decays with gluons (θ -> Wg)



Exclusive Mjj Spectrum





FeynRules (model file)

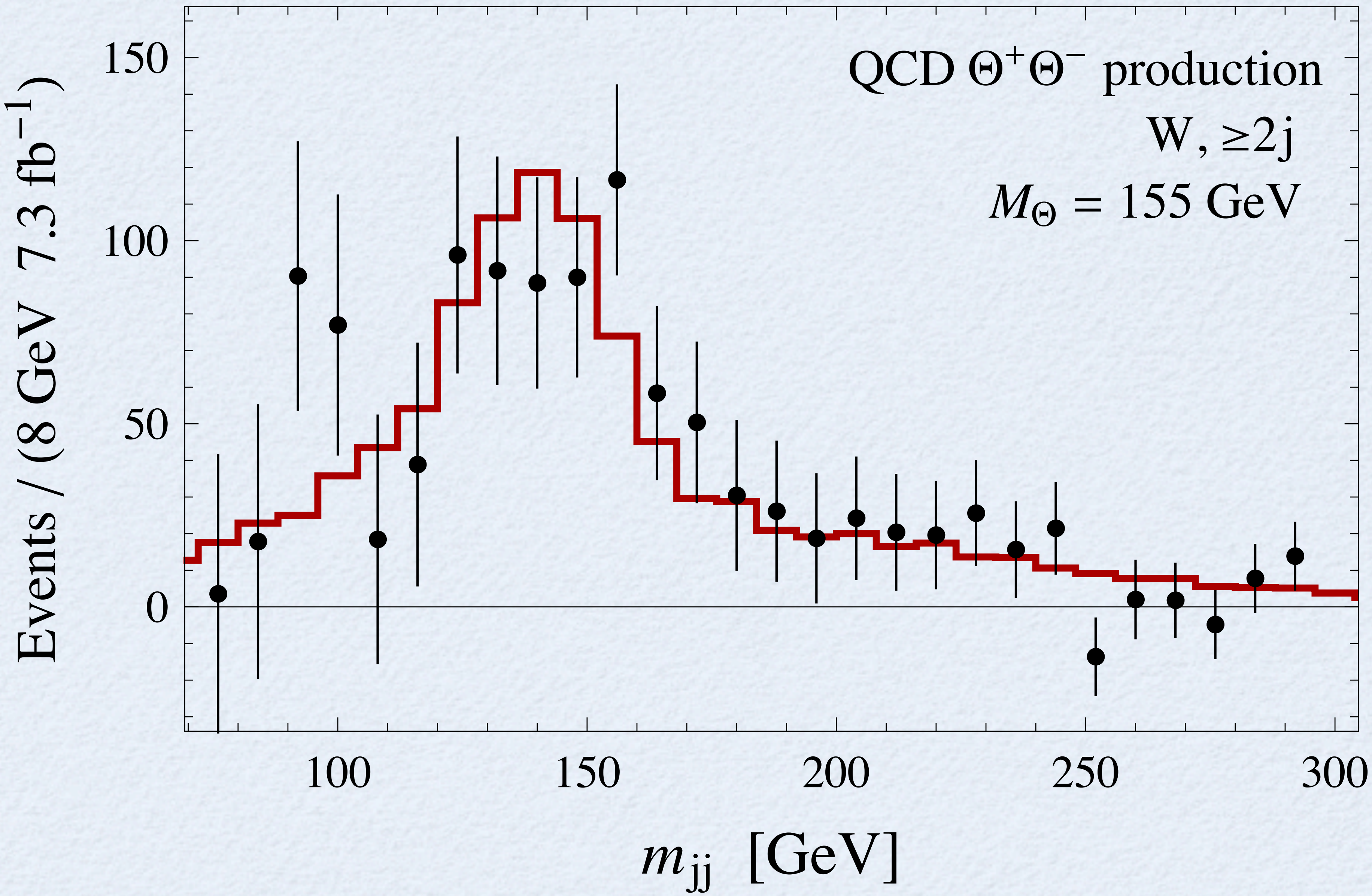
MadGraph5 (parton events)

Pythia (parton shower)

PGS (detector simulation)

2 σ x Br(Wbb) x Br(jj) = 3.2 pb
Br(Wbb) = 40 %

Inclusive Mjj Spectrum



2σ x Br(Wbb) x Br(jj) = 3.2 pb using Br(Wbb) = 40 %
before cuts, without W branching fraction

Resonant Production Through "Coloron"

New interaction with coloron G′

$$g_s \frac{1-\tan^2\phi}{2\tan\phi} f^{abc} G'^a_\mu \left[\left(\Theta^{b+}\partial^\mu\Theta^{c-} + \mathrm{H.c.}\right) + \Theta^{b0}\partial^\mu\Theta^{c0}\right]$$

Single coloron production proceeds only from qq initial states

Decays mostly to scalar pairs

$$\Gamma(G' \to \Theta^+\Theta^-) = \frac{\alpha_s M_{G'}}{16\tan^2 2\phi}\left(1 - \frac{4M_\Theta^2}{M_{G'}^2}\right)^{3/2}$$

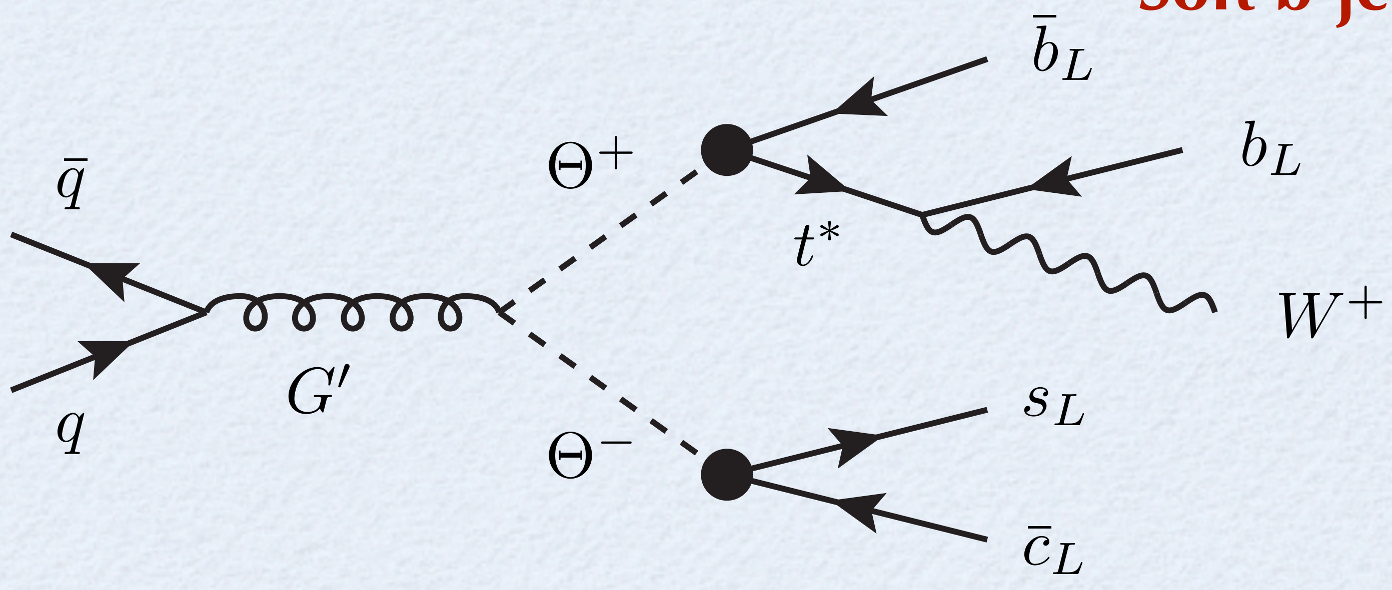
Quark couplings suppressed $g' = g_s \tan\phi \ll g_s$

$$\Gamma(G' \to q\bar{q}) = \frac{\alpha_s}{6}\tan^2\phi\, M_{G'}\left(1 - \frac{4M_q^2}{M_{G'}^2}\right)^{3/2}$$

for tan $\phi \approx 0.1$ model is completely safe from dijet searches.

Resonant Octo-triplet Production

Soft b-jets



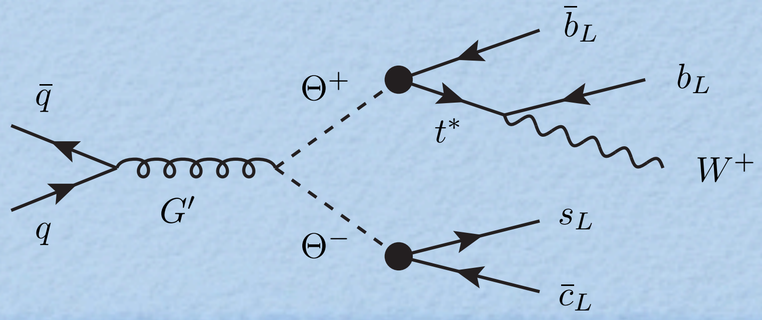
Wjj survive cuts

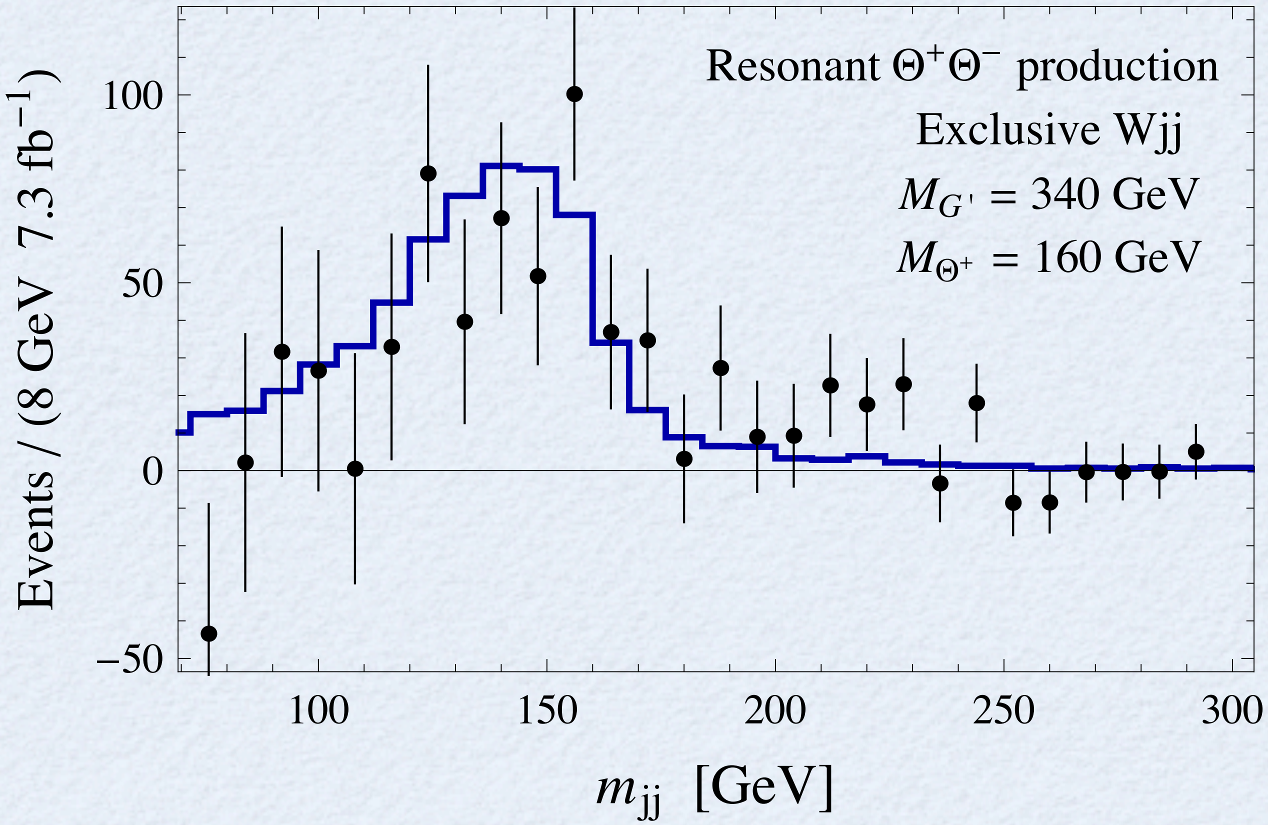
Strategy: decrease QCD, enhance Coloron

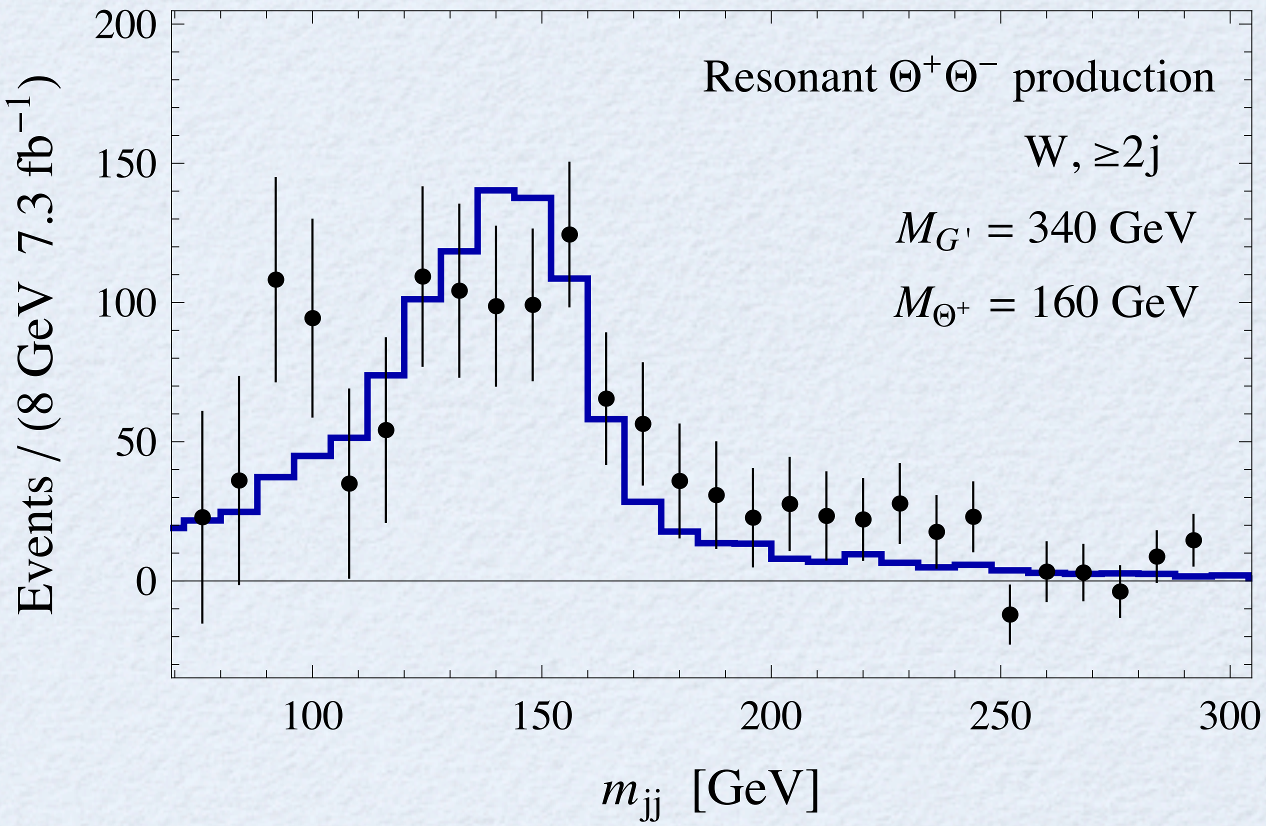
1. Decrease Br(Wbb) from 40% to 4% => Kills QCD Wjj signal (4jet events dominate)

2. Total cross section very sensitive to width.
Pick tanϕ to modify coupling and width to get large coloron signal.

CDF Dijet excess revisited





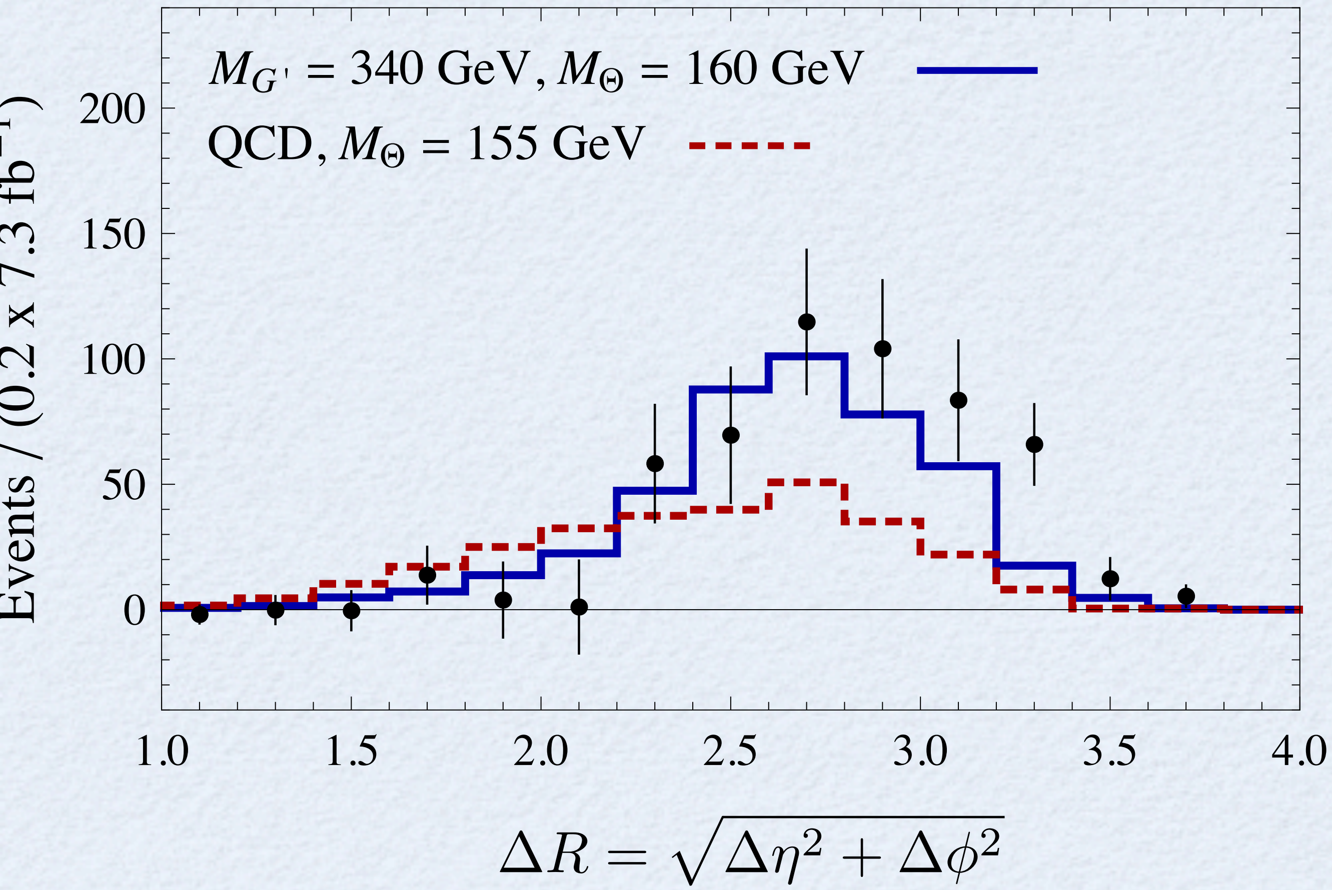


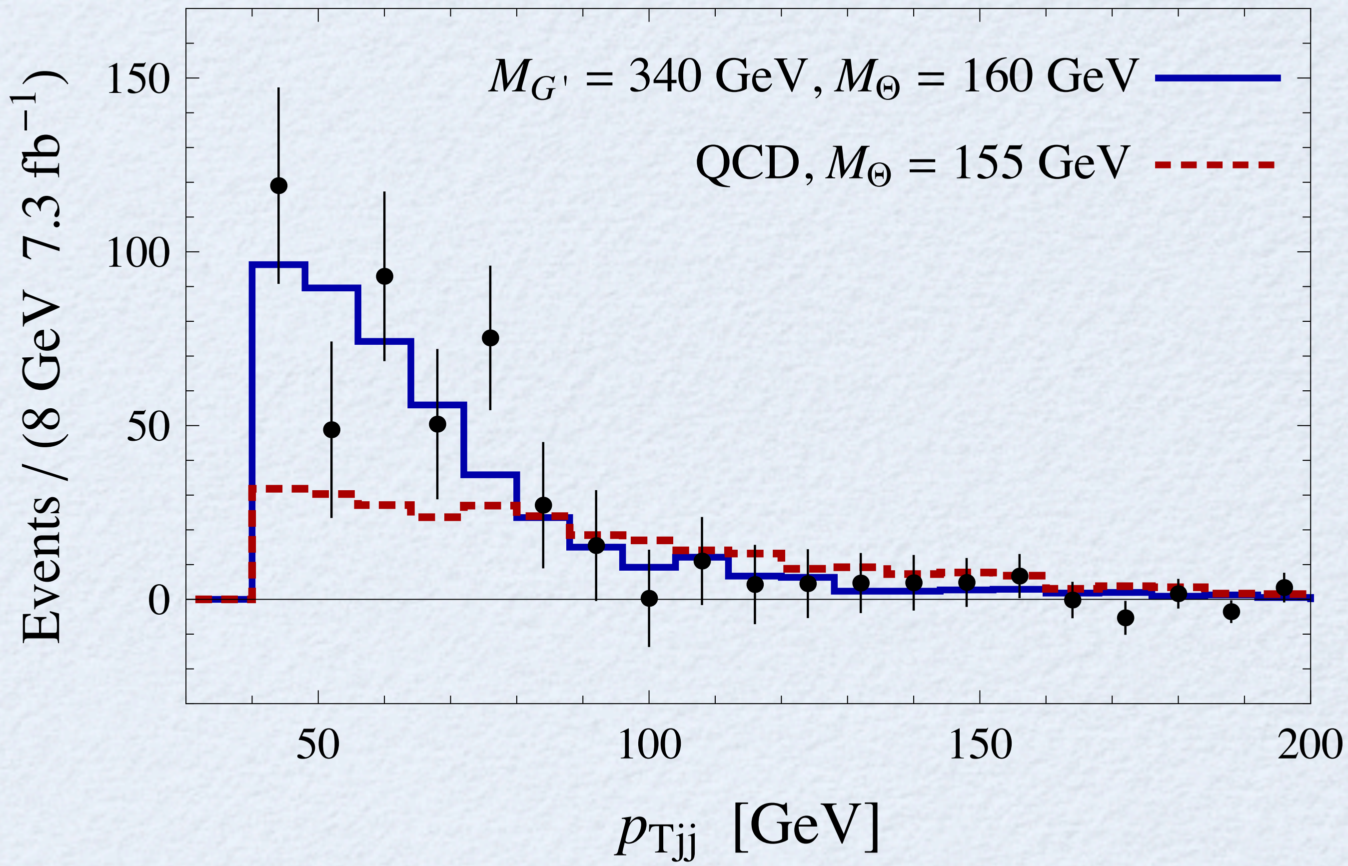
Br(Wbb) = 4 %, Γ = 6.5 GeV, tanϕ = 0.15, σ x Br = 3.8 pb

Very good fit, but unlike QCD production, misses the tail.

So far, no clear winner, but ...

Other Kinematic Distributions





Data from signal window (115 GeV < Mjj < 175 GeV)

Resonant production (blue) is the clear winner

Excesses all consistent with resonant new physics

LHC Cross Sections

Benchmark QCD and production rates (not including acceptances)

$$\sigma\big(pp \to \Theta^+\Theta^- \to (jj)(\ell\nu b\bar{b})\big) \simeq 52 \text{ pb}$$

$$\sigma\big(pp \to G' \to \Theta^+\Theta^- \to (jj)(\ell\nu b\bar{b})\big) \simeq 10 \text{ pb}$$

Naive estimate: assume same acceptances as CDF (few %).

QCD production predicts few hundred events at 1/fb

Coloron cross section even smaller with quark initial state

Should be verified or ruled-out in a few months

Conclusion

- CDF Wjj plots consistently suggest new physics
- D0 “null” result not complete (thesis suggests possible bump)
- Octo-triplets decaying through dimension 5 operators can explain the dijet bump
- Resonant production of octo-triplets gives better fit to other distributions
- Higher dimension operators may contribute to B meson mixing
- Predicts resonances in (Wbb)(jj), (Wbb)(Wbb), and (jj)(jj) signals